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Using virtual reality to investigate physical environmental factors related to cycling in older adults: A comparison between two methodologies

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ABSTRACT

Introduction: Cycling has a positive impact on physical, mental and social health, and slows the aging process. However, there is still a large potential to increase the cycling levels in Belgian older adults. In order to promote cycling for transport, safe and attractive street characteristics have previously been investigated by using cross-sectional surveys and manipulated photographs. As VR-technology is still rarely used in transportation research, the aim of this study was to develop and compare the use of two different novel VR-applications, i.e. cycling in a 3D-CAVE and cycling with a VR-headset, as experimental approaches with regard to the sense of presence, the representation of the reality, and simulator sickness. Furthermore, the moderating effects of personal characteristics and test sequence were investigated.
Methods: In total, 108 older adults (≥65 years) participated in the cross-over experiment. The participants performed two cycling tests (i.e. cycling through virtually displayed existing streets in Ghent) using both VR-applications (3D-CAVE and VR-headset) in random order. After each cycle test, participants had to complete the same questionnaire.
Results: Both VR-methodologies are equally good to be used among older adults (≥65 years) in future research, i.e. identify which characteristics in the physical environment have an impact on cycling for transport. Additionally, there are no specific requirements for particular target groups regarding the kind of VR-application. General preference was given to the test setup that was completed in second place, indicating the importance of habituation to the virtual environment.
Conclusions: Both VR-applications can be used in future research. The advantage of the VR-headset in comparison to the 3D-CAVE, is that the VR-headset is more practical to use at

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different locations. Especially in regard to the older populations, it is more convenient to bring the test setup closer to the subjects themselves.

1. Introduction

Physical activity (PA) is an effective strategy to reduce the prevalence of chronic diseases (World Health Organization, 2015, 2010), depression or dementia (Jackson et al., 2016) and to reduce their associated health care costs (Rechel et al., 2009). Given that older adults (≥65 years) are globally the fastest growing age segment, with many suffering from chronic diseases and 60–70% not achieving sufficient PA to obtain health benefits (European Commission, 2014; World Health Organization, 2011), there is a strong need to promote PA at a regular basis in this population.

Active transport, i.e. walking and cycling to a destination, is an ideal activity to promote among older adults, as it is healthy, accessible, well-liked and easy to integrate in an older adult's daily routine (De Fré et al., 2011; Dhondt et al., 2013; Edwards and Mason, 2014; Mueller et al., 2015; Woodcock et al., 2014). Cycling enables to cover greater distances than walking and, hence, carries the possibility to increase older adults' action radius (Mandl et al., 2012). Cycling is a moderate to high intensive form of physical activity (Ainsworth et al., 2000) which slows the aging process (Mazzeo and Tanaka, 2001) and has a positive impact on cognitive functioning as well as social and psychological health (Garrard et al., 2012). Unfortunately, the prevalence of cycling for transport in this age group is still alarmingly low. Among older adults in Belgium, almost two-third of all trips are still made by car, of which 50% and 60% of these trips are shorter than 3 and 5 km respectively which is a feasible distance to cycle (Declercq et al., 2016). Consequently, there is still a large potential to increase the cycling levels in Belgian older adults.

An important prerequisite to develop effective interventions to promote cycling, is to identify the factors that are related to cycling (i.e. correlates) among this specific age group (Baranowski et al., 1998). A recent systematic review showed that aspects of the neighborhood physical environment (e.g. residential density, street connectivity, overall access to destinations/services, land use mix, pedestrian-friendly features) are associated with the level of physical activity among older adults and are likely to have a large-scale, population-level effect (Cerin et al., 2017). Nonetheless, concerning cycling for transport, only limited evidence is available on environmental correlates, and moreover the available evidence is especially from cross-sectional nature (Cerin et al., 2017).

Stronger experimental designs are needed. However, natural experiments or environmental adaptations conducted in real-life settings are usually long-term projects, involve high costs and allow limited control by the researchers. Therefore, an innovative and cost-effective experimental approach with manipulated photographs was introduced to investigate the physical micro-environmental correlates (i.e. street characteristics) of cycling for transport among older adults (Van Cauwenberg et al., 2019). From this research, results indicated that the provision of well-separated cycle paths should be considered as a priority to encourage cycling for transport among older adults relative to traffic density, cycle path evenness, distance, speed limit, overall upkeep, vegetation and traffic calming devices (Van Cauwenberg et al., 2019). However, in real life, people perceive and experience their environment differently depending on their speed of travel (Heft and Nasar, 2000). Computer-generated 3D Virtual Reality (VR) environments offer the unique opportunity to overcome the limitations posed by 2D photographs (Cubukcu and Nasar, 2005), provide much more realistic test results (Natapov and Fisher-Gewirtzman, 2016), and consequently can be an important next step in experimental research before conducting actual changes in real life.

VR-technology has been rarely used in transportation research, or not widely described in the scientific literature. Moreover, in the few available previous studies, control equipment (e.g., a joystick) was used to explore the virtual environment (Yuan et al., 2014). A more realistic simulation might be created when participants have to cycle on a stationary bicycle while navigating through the virtual environment. As research using VR-technology is still scarce, a first step in VR-research is to ascertain which type of VR-application is best and most feasible to use, taking into account different parameters of user experience (e.g. sense of presence, simulator sickness, representation of the reality). The two most common VR-applications are the 3D-CAVE (i.e. Computer Aided Virtual Environment) which is a cubic space where the walls are used as projection screens (Cruz-neira et al., 1993), and the VR-headset which is a head-worn apparatus that completely covers the eyes, receiving no longer information from the real environment (Fuchs, 2017).

The quality of VR-experience can be evaluated using different parameters. First, the 'sense of presence' is the subjective sense or feeling of being in a virtual environment (Schubert, 2003), which can be developed by travelling through and interacting with virtual environments (Schubert and Friedmann, 1998). It is a central issue for VR (Steuer, 1992), as the higher the sense of presence is, the more meaningful the virtual environment is perceived (Witmer and Singer, 1998). Therefore, it is important to investigate which VR-methodology could mostly enhance the sense of presence. As 'representation of the reality' is a second important parameter related to VR-experience (Cubukcu and Nasar, 2005; Natapov and Fisher-Gewirtzman, 2016), it might be interesting to investigate if there is a difference in representation of the reality between the two different methodologies. Third, 'Simulator sickness' is a syndrome similar to motion sickness which can occur during use of simulators and VR-exposure (Duzmanska et al., 2018; Kennedy and Norman, 1993). As the experience of simulator sickness symptoms is related to the risk of dropout (Matas et al., 2015), it is important to investigate which VR-methodology has the lowest experience of simulator sickness. Furthermore, it has been demonstrated that females, people with a history of motion sickness and older adults are a high-risk group for simulator sickness (Matas et al., 2015). Therefore, it might be interesting to investigate if there are differences in VR-parameters of the two methodologies regarding socio-demographic characteristics of the participants.

The aim of this study was to develop and compare the use of two different novel VR-applications, i.e. cycling in a 3D-CAVE and cycling with a VR-headset, as experimental approaches with regard to the sense of presence, the representation of the reality, and simulator sickness. Furthermore, the moderating effects of personal characteristics and test sequence were investigated. Based on this preliminary investigation, a well-founded choice can be made regarding the method that will be used in follow-up research.

2. Material and methods

2.1. Sampling and study design

Flemish older adults (≥65 years) were recruited by purposeful convenience sampling (Portney and Watkins, 2009). Digital and paper flyers were distributed in neighborhood health centers, local service centers, senior organizations, social media groups, and through family and friends of the researchers. Furthermore, this research was announced on local TV (Smet, 2019) and radio stations. The participants were able to register via various channels to participate in the study. People could register via e-mail, text message, or a website (https://gentfietst.webnode.be) to express their interest to participate in this research. Finally, their appointment was scheduled by phone or by email. The study protocol was approved by the Ghent University Hospital Ethics Committee (registration number B670201834807).

At the test location, participants first gave written consent for participation in the experiment. The experiment used a cross-over design (see Fig. 1). The participants were asked to perform two cycling tests (i.e. cycling through virtually displayed existing streets in Ghent) using both VR-applications (3D-CAVE and VR-headset, see Fig. 2) in random order. After each cycle test, participants had to complete the same questionnaire (questionnaire 1), followed by a general questionnaire (questionnaire 2) at the end. Each question together with the answer options was read aloud by the researcher, while the participant could read along on a large computer screen. The researcher digitally registered the responses of the participants and provided additional explanations where necessary.

First, under supervision of a researcher, the participant took place on a stationary ladies' bike on rollers with brakes and gears. For each VR-application, the participants were given a few minutes to get used to cycling in the virtual environment in a simulated training environment (i.e. concrete road with cones) without traffic (see Fig. 3). If necessary, the saddle height was adjusted and the participant could choose a comfortable gear. After getting used to the experimental setup, the streets were presented in random order so that the participant cycled through each of the three streets of Ghent (see Fig. 3): one urban, one semi-urban and one rural street. The same protocol was conducted for the two experiments using the different set-ups. During the entire experiment, the researcher was standing next to the bike for safety reasons.

Every participant was able to stop the experiment at any time and without justification. Also when the participant gave non-verbal signals (such as dizziness, sighs or nausea), the researcher emphasized that the test could be ended if desired. The total investigation took 30–45 min. Upon completion of the study, the participants received a gift voucher from the city of Ghent.

2.2. Experimental setups

A 3D-CAVE (i.e. Computer Aided Virtual Environment) is a VR-environment that consists of a cubic space, where the walls are used as projection screens (Cruz-neira et al., 1993). A three-walled 3D-CAVE, made by the 3D-team of the city of Ghent, was used within this research setting (see Fig. 2, left panel). Three retro projection screens were tensioned in an aluminium frame of about 3.2 m. Three projectors (i.e.Nec 3500 Lumen, extra focus lens, short throw 0.8) and one computer were used, installed outside the CAVE. This means that the bicycle on rollers was located in the middle of the 3D-CAVE, between three screens (front wall, left wall, right wall) on which the virtual environment was projected. Two sensors were attached on the bike, one at the steering wheel (using a 3D-print to hold the sensor) and one at the rear wheel, which reported rotations, movements forwards, and accelerations.

An Arduino interface was used between the bike sensors and the computer. The second methodology uses the same bike and technical interfaces, but used a HTC Vive branded VR-headset. The VR-headset showed the virtual environment immediately on the retina, and the participants no longer received information from the real environment because the VR-headset completely enclosed the eyes (see Fig. 2, right panel). Both methodologies have a first person perspective, i.e. the participant views the simulation from the perspective of the character (Kozhevnikov and Rupali, 2012).

2.3. VR-environment

In collaboration with the 3D-team of the City of Ghent, the virtual environment was modelled by using 3D-studio max and Blender (Matthys, 2014). After texturing the modelling of streets and buildings, this was augmented with cars, trees and other characteristics of the public domain. 3D-game engine Unity was used to animated some objects (i.e. cars ride through the street, and people walking around). One training environment without traffic (i.e. concrete road with cones) and three existing streets with a different degree of

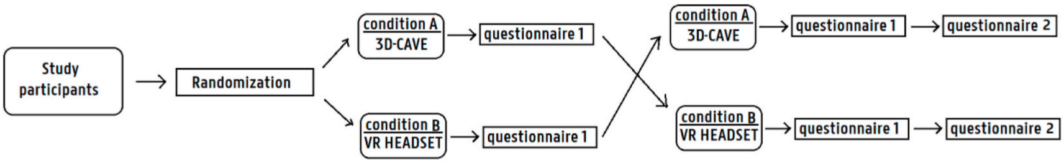

Fig. 1. Cross-over design used in this study.

Fig. 2. 3D-CAVE (left) vs. VR-headset (right).

urbanization were virtually simulated (see Fig. 3): one urban (i.e. Vlaanderenstraat, Fig. 3.2), one semi-urban (i.e. Dendermondsesteenweg, Fig. 3.3) and one rural street (i.e. Dries, Fig. 3.4).

2.4. Measures

2.4.1. Sense of presence, representation of the reality, and simulator sickness

Two questionnaires were administered of which the first questionnaire was completed twice immediately after completing both experiments (i.e. see Fig. 1, questionnaire 1). Questionnaire 1 assessed the sense of presence, how realistic the VR-environment was perceived and simulator sickness. The questionnaire consisted of existing validated questionnaires: the Igroup Presence Questionnaire (IPQ) (Schubert et al., 1999) and the Simulator Sickness Questionnaire (SSQ) (Kennedy and Norman, 1993). An abbreviated version of IPQ (Dutch version) was used to measure the sense of presence. This questionnaire consists of 7 items assessed on a five-point scale, including the following scales: general presence, spatial presence, involvement, experienced realism (Schubert et al., n.d.). All items

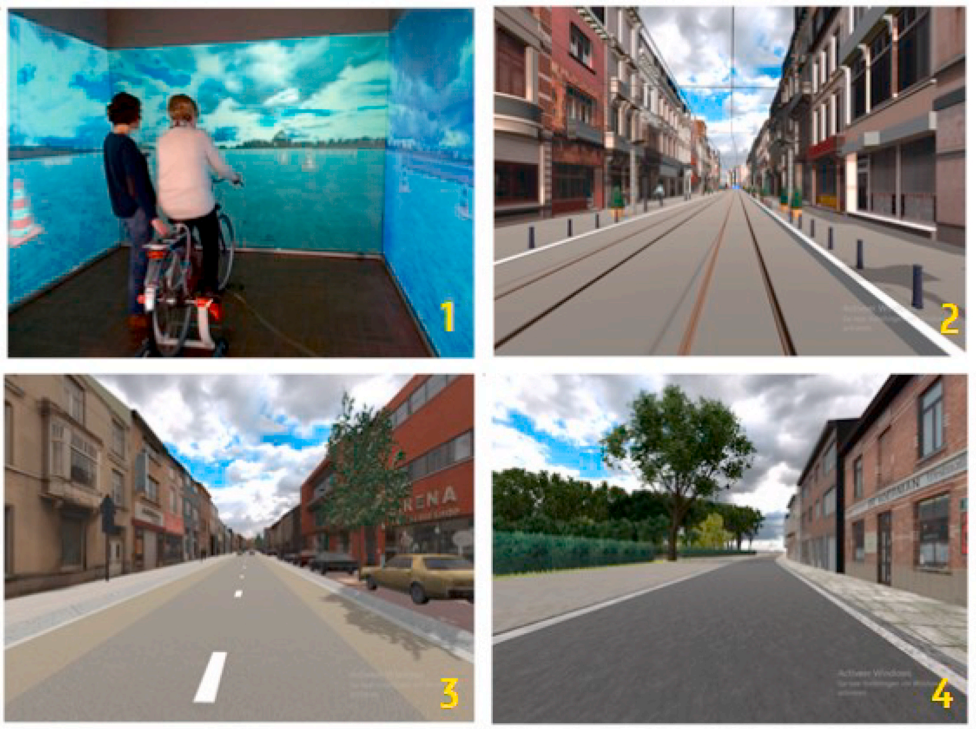

Fig. 3. The training environment (1), Vlaanderenstraat (2), Dendermondsesteenweg (3) and Dries (4) in Virtual Reality.

were summed to one scale of which the Cronbach's alpha for the IPQ in the current sample was 0.80. Furthermore, the SSQ is used to measure the simulator sickness and consists of 16 items (Kennedy and Norman, 1993). An additional answer option was added to the original 4-point Likert scale from 'none' to 'severe' to achieve a 5-point Likert scale. In the present sample, internal consistency was found to be good (Cronbach's alpha = 0.89). All items were translated into Dutch. One total simulator sickness score was obtained by summing up the different items using unit weights, see Kennedy and Norman (1993) for the used formula. Finally, participants had to assess how realistic they perceived the different street characteristics presented in the VR-environment (i.e. cars, road, cycle path, sidewalk, movement of the traffic, the pedestrians, buildings/facades, trees/greenery) on a five point-Likert scale from 'not realistic at all' to 'completely realistic'. An additional answer option 'not paid attention to' was also added, and was encoded as missing. One scale was created by summing up all those items (Cronbach's alpha = 0.87).

2.4.2. Personal characteristics and test sequence

Questionnaire 2 was completed at the end of the experiment and assessed socio-demographic information (i.e. age, gender, living status, education, resident of Ghent, length and weight to calculate BMI), cycling behavior, screen behavior, and the participants' experience with VR. A detailed description of the different assessed items and answer categories can be found in Table 1. Their screen-related behavior was assessed on a five-point Likert scale from 'never' to 'very often' and was the sum of their use of the smartphone, TV, laptop/computer, tablet, games.

2.5. Statistical analyses

In total, 118 older adults participated in the experiment. Five participants were a little younger than 65 years, four participants did not complete the experiment and from one participant the demographic information was lacking according to technical problems. This resulted in an analytical sample of 108 participants.

Table 1
Descriptive characteristics of the participants (n = 108).

Personal characteristics	
Age in years (M ± SD)	70.34 ± 5.38
<75 years (%)	82.4
≥75 years (%)	17.6
Women (%)	44.4
Living alone (%)	23.1
Tertiary education (%)	61.1
BMI (M ± SD)	24.8 ± 3.3
underweight (%)	1.9
normal weight (%)	50.9
overweight (%)	41.7
obesity (%)	5.6
Resident of Ghent (%)	
Yes	77.8
No	22.2
Never been in contact with VR-applications (%)	76.5
Screen-related behavior (M ± SD) [a]	3.10 ± 0.69
Transport behavior	
Do you still drive a motorized vehicle yourself (%)	
Yes	86
No	14
Do you still ride a bicycle (%)	
Yes	94.4
No	5.6
Which type of bicycle do you ride? (%)	
regular bicycle	52.3
electric bicycle	18.7
regular and electric bicycle	18.7
Other	10.3
Frequency cycling for transport (%)	
less than once a month	15
1–3 days/month	3.7
1–2 days/week	21.5
3–4 days/week	17.8
5–7 days/week	42.1

M = mean; SD = standard deviation; [a] assessed on a 5-point scale ranging from 1 (=never) to 5 (=always); [b] assessed on a 5-point scale: 1 = certainly the 3D-CAVE, 2 = rather the 3D-CAVE, 3 = no preference, 4 = rather the VR-headset, 5 = certainly the VR-headset.

All analyses were performed in SPSS 24.0 software. First, the descriptive statistics were calculated for the total sample. Second, to compare both methodologies regarding the 'sense of presence', 'representation of the reality' and 'simulator sickness', a repeated measures MANOVA was performed. The multivariate Wilks' lambda and the univariate Sphericity assumed values were interpreted with the corresponding descriptives if significance was found. Third, the moderating effect of test sequence (started with the 3D-CAVE vs. started with the VR-headset) was examined using a repeated measures MANOVA with a between factor. After this, the moderating effects of sex (men vs. women), age (<75 years vs. ≥ 75 years), BMI (<25 kg/m^2 vs. ≥25 kg/m^2), education level (non-tertiary education vs. tertiary education), screen-related behavior (dichotomized based on the median; (<3.2 vs. ≥ 3.2), and previous contact with VR-applications (never been in contact with VR-applications vs. at least once been in contact with VR-applications) were examined. These latter analyses were adjusted for test sequence. Finally, additional sensitivity analyses (i.e. repeated measures MANOVAs) were conducted in order to eliminate the effect of test sequence, i.e. we considered the results of the first test, independent of the second test. Plots and corresponding descriptives were reported from the significant interaction effects. Level of significance was defined at $\alpha = 0.10$ (trend) and $\alpha = 0.05$.

3. Results

3.1. Descriptive statistics

The descriptive characteristics (i.e. socio-demographics, transport behavior, VR-characteristics) of the study population are presented in Table 1. The sample consisted of 108 participants ranging in age from 65 to 89 years: 44.4% were women, 23.1% lived alone, 61.1% had followed tertiary education (college, university or postgraduate), 77.8% lived in Ghent and the mean BMI was 24.8 ± 3.3 kg/m^2. More than 52.3% of the participants still rode a regular bike and 42.1% cycled on average 5–7 days/week for transport. Almost 80% of the current sample had never been in contact with VR-applications.

3.2. Main effects: comparison between the two methodologies regarding sense of presence, perception of the reality and simulator sickness

Results from the repeated measures MANOVA showed that 'the sense of presence', 'perception of the reality', and 'simulator sickness' were significantly different between the two methodologies ($F = 6.001$, $p = 0.001$). Participants perceived a significantly lower sense of presence ($F = 4.470$, $p = 0.037$), a lower perception of the reality of the environment ($F = 3.664$, $p = 0.058$), and a lower simulator sickness ($F = 6.801$, $p = 0.010$) using the 3D-CAVE in comparison to the VR-headset. See Table A.1 in Appendices for the corresponding means and standard deviations.

3.3. Moderating effects of test sequence

For the test sequence, we found a significant multivariate interaction effect between test sequence and methodology ($F = 12.210$, $p < 0.001$) for the combination of the three independent variables, as well as univariate interaction effects between test sequence and methodology (see Fig. 4) for 'sense of presence' ($F = 14.291$, $p < 0.001$), 'reality of the environment' ($F = 11.498$, $p = 0.001$), and 'simulator sickness' ($F = 20.165$, $p < 0.001$). Overall, participants who started the experiment with the 3D-CAVE, perceived a significantly higher sense of presence, a higher perception of the reality and a lower degree of simulator sickness in the VR-headset in comparison to participants who started with the VR-headset. In contrary, participants who started with the VR-headset perceived a significantly higher sense of presence, a higher perception of the reality, and a lower degree of simulator sickness in the 3D-CAVE in

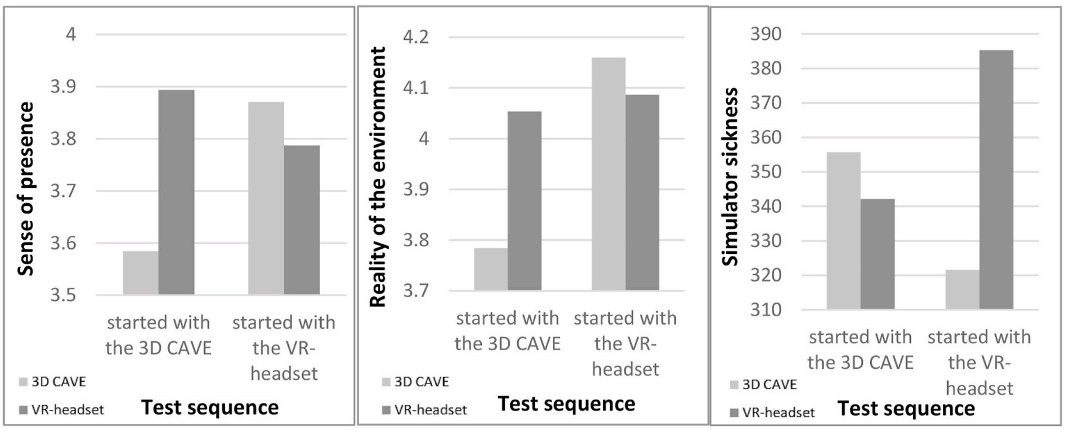

Fig. 4. Interaction effect between test sequence and methodology for sense of presence, simulator sickness and reality of the environment.

comparison to participants started with the 3D-CAVE. Table A.1 in Appendices represents the corresponding means and standard deviations.

3.4. Moderating effects of sex, age, BMI, educational level, screen-related behavior, previous contact with VR-applications, adjusted for test sequence

All results of the multivariate and univariate interaction effects with each moderator and the used methodology can be found in Table 2. No univariate significant interaction effects were found between age and methodology and between gender and methodology (adjusted for test sequence), meaning that there is no difference in sense of presence, perception of reality and simulator sickness depending on the kind of methodology (3D-CAVE vs. VR-headset) between participants younger than 75 years and participants older than 75 years and between men and women. Independent of the methodology, a significant main effect of age for 'sense of presence' was found ($F = 4.448$, $p = 0.037$): participants older than 75 years perceived significantly more presence (4.0 ± 0.5) than participants younger than 75 years (3.7 ± 0.7). Additionally, independent of the methodology, a significant main effect of sex was present for 'simulator sickness' ($F = 9.720$, $p = 0.002$) with women perceiving a higher degree of simulator sickness (391.2 ± 141.6) than men (319.1 ± 98.9).

Table 2
Multivariate en univariate interaction-effects.

SEX (men vs. women)					
IE (method*sex)	F	p	ME (sex)	F	p
Multivariate	1.625	0.188	Multivariate	3.453	0.019
Univariate			Univariate		
Presence	1.711	0.194	presence	0.066	0.798
SSQ	2.732	0.101	SSQ	9.720	0.002
Reality	0.610	0.437	reality	0.006	0.941
AGE (<75 years vs. ≥75 years)					
IE (method*age)	F	p	ME (age)	F	p
Multivariate	1.072	0.364	Multivariate	1.558	0.204
Univariate			Univariate		
presence	1.122	0.292	presence	4.448	0.037
SSQ	1.532	0.219	SSQ	0.092	0.763
reality	0.010	0.921	reality	1.116	0.293
BMI (<25 kg/m2 vs. ≥25 kg/m2)					
IE (method*BMI)	F	p	ME (BMI)	F	p
Multivariate	0.387	0.762	Multivariate	0.101	0.959
Univariate			Univariate		
presence	0.816	0.368	presence	0.299	0.586
SSQ	0.003	0.956	SSQ	0.012	0.911
reality	0.146	0.703	reality	0.155	0.695
EDUCATION (non-tertiary education vs. tertiary education)					
IE (method*education)	F	P	ME (education)	F	p
Multivariate	1.387	0.251	Multivariate	1.027	0.384
Univariate			Univariate		
presence	1.431	0.234	presence	2.334	0.130
SSQ	1.727	0.192	SSQ	0.035	0.852
reality	0.638	0.426	reality	1.750	0.189
SCREEN-RELATED BEHAVIOR (dichotomized based on the median; (<3.2 vs. ≥3.2)					
IE (method*screen-related behavior)	F	p	ME (screen-related behavior)	F	p
Multivariate	0.972	0.409	Multivariate	1.105	0.351
Univariate			Univariate		
presence	1.554	0.215	presence	2.098	0.150
SSQ	0.898	0.345	SSQ	0.120	0.729
reality	0.450	0.504	Reality	2.006	0.160
PREVIOUS CONTACT WITH VR (never vs. at least once been in contact with VR-applications)					
IE (method*previous contact VR)	F	p	ME (previous contact VR)	F	p
Multivariate	0.863	0.463	Multivariate	1.716	0.168
Univariate			Univariate		
presence	0.114	0.736	presence	1.264	0.264
SSQ	1.828	0.179	SSQ	0.623	0.432
reality	0.549	0.460	reality	3.374	0.069

IE = interaction-effect; ME = main-effect.

For BMI, education, screen-related behavior and previous contact with VR-applications, no multivariate or univariate interaction effect with methodology was found for 'sense of presence', 'reality of the environment', and 'simulator sickness'. Additionally, independent of the methodology, no significant main effects of BMI, education and screen-related behavior were found. Only for previous contact with VR-applications, a trend towards a significant main effect for 'reality of the environment' was found ($F = 3.374$, $p = 0.069$). Participants who had never been in contact with VR-applications perceived the environment as more realistic (4.1 ± 0.1) in comparison to participants who had at least once been in contact with VR-applications (3.9 ± 0.1).

3.5. Sensitivity analyses

Since an effect of test sequence was found, a sensitivity analysis was conducted to eliminate the effect of test sequence. First, we only considered the results of the first test, independent of the second test, where participants had a minimal habituation period, only a few minutes to get used to cycling in the virtual environment in a simulated training environment. Results from the MANOVA showed a marginally significant difference in 'the sense of presence', 'simulator sickness' and 'perception of reality of the environment' between the two methodologies ($F = 2.203$, $p = 0.092$). Only regarding 'the perception of reality of the environment' ($F = 3.664$, $p = 0.059$), participants perceived a significant trend to a higher perception of reality of the environment using the VR-headset ($M = 4.1$, $SD = 0.9$), in comparison to the 3D-CAVE ($M = 3.8$, $SD = 0.8$). Furthermore, no significant difference was found between the two different methodologies regarding 'the sense of presence' ($F = 2.078$, $p = 0.152$) and 'simulator sickness' ($F = 1.536$, $p = 0.218$).

4. Discussion

The aim of this study was to compare the use of two different novel VR-applications (i.e. cycling in a 3D-CAVE and cycling with a VR-headset) as experimental approaches with regard to the sense of presence, simulator sickness and perception of reality of the environment among older adults. Furthermore, the test sequence was also taken into account and the moderating effects of sex, age, BMI, education level, screen-related behavior, and previous contact with VR-applications were investigated.

The current study showed no prominent difference between the two methodologies/VR-applications. In general, preference was given to the test setup that was completed secondly. The test sequence proved to be a very important factor in determining differences in the sense of presence, simulator sickness, and perception of reality of the environment between the two methodologies. The VR-application that was tested secondly, always scored better, i.e. a higher sense of presence, a lower degree of simulator sickness and a higher perception of the reality was experienced. Although a cross-over design was used in the present study, a significant interaction effect between the VR-methodology and the test sequence was found. This interaction effect may indicate a carryover effect (also known as an order effect), whereby the second condition is influenced by exposure to the first condition (Jones and Kenward, 2014). The risk of a carryover effect might be reduced (Johnson, 2010; Jones and Kenward, 2014; Mills et al., 2009; Polit and Beck, 2017) by integrating a washout period (i.e. the effect of the exposure to the first condition must have disappeared before the participant is exposed to the second condition) (Johnson, 2010; Polit and Beck, 2017). The washout period (i.e. filling in a questionnaire) in our research design was probably not long enough to completely disappear the exposure of the first condition. Additionally, the carryover effect may indicate that habituation to a virtual environment probably plays a role in the experiencing presence, perception of reality of the environment, and simulator sickness. Previous research also indicated that the attitude of older adults towards VR-changes from neutral to positive after an initial exposure (Huygelier et al., 2019). Nonetheless, no moderating effect of previous contact with VR-applications was found in our study, we assume that they needed a habituation period probably even more because the majority of our sample had never been in contact with VR (76.5%), or if they have already had an experience with VR, it probably will not be to a large extent. Previous research in Flanders (Belgium) showed similar statistics, only 34% of adults older than 65 years know VR, in comparison to respectively 76% of the 16–24 years old, 83% (25–34 years), 79% (35–44 years), 69% (45–54 years), and 51% (55–64 years) (Vanhaelewyn and De Marez, 2018). Therefore, we suggest that the effect of sequence, or the habituation period, may be much smaller among other age groups that are more accustomed to VR.

Moreover, also according to sex, age, BMI, educational level, and screen-related behavior, no significant differences were found between the kind of methodology (3D-CAVE vs. VR-headset) and sense of presence, perception of reality of the environment, and simulator sickness. These results indicate that there are no specific requirements for particular target groups regarding the kind of VR-application. However, for future research it might be interesting to take into account the significant main effects, independent of the VR-methodology. Our results indicated, in line with previous research (Boyd, 2014; Koslucher et al., 2015; Matas et al., 2015; Munafo et al., 2017), that women perceived a higher degree of simulator sickness than men. Nevertheless, it is widely accepted that women are at greater risk of motion sickness than men (Munafo et al., 2017), this result might be a call to designers to develop VR-applications that decrease the discriminatory gender effects. Furthermore, our present results indicated that participants older than 75 years significantly perceived more presence in comparison to participants younger than 75 years. In the literature, there is no consensus on the influence of age on the degree of presence. A previous research indicated a negative correlation between age and presence among 5–54 years old (Bangay and Preston, 1998), while another study among adults (18–62 years) showed a positive correlation (Schuemie et al., 2005). As research among older adults and VR is scarce, future research has to investigate this relation in more detail. Lastly, our results indicated that participants who had never been in contact with VR-applications perceived the environment as more realistic in comparison to participants who had at least once been in contact with VR-applications. This result indicates that if we are going to test other age groups that have already experience with VR, the experimental environment will have higher demands.

Our results indicated that to increase the sense of presence, improve the perception of reality of the environment, and decrease the simulator sickness, it might be important to give the participant sufficient time to get used to the virtual environment (i.e. habituation time) when using a VR-application in future research. The literature shows that previous experiences with VR are positively associated with presence, because the VR-experience becomes more meaningful (Witmer and Singer, 1998). A recent study of Fransson et al. (2019) indicated that participants could get used to VR-visuals and consequently respond better to those VR-visuals (Fransson et al., 2019). Furthermore, a recent review indicated that simulator sickness could be reduced by repeated virtual exposure and observed this in different study designs, e.g., with a couple of VR-exposures on separate days or on 1 day and with a single, prolonged VR-exposure (Duzmanska et al., 2018). In our study, participants received only a few minutes to get used to cycling in the virtual environment in a simulated training environment. Those few minutes might be insufficient to get used to the VR-exposure. Therefore, it is advisable to further investigate exactly how long the training moment (exposure) should be in order to give the two methodologies a fair chance. Future research needs to determine how many repetitions are needed in order to filter out the influence of habituation. Previous research already indicated that for better habituation, the number of exposures appears to be more important than the time interval between those exposures (Howarth and Hodder, 2008). However, more research on this topic is needed as we have to bear in mind that the VR-technology still evokes unpleasant experiences. We also noticed this in our research four subjects did not complete the experiment because of unpleasant symptoms. Therefore, it is important as researcher to pay attention to non-verbal signals (such as dizziness, sighs or nausea) during testing with VR, and to keep in mind that every participant has to be able to stop the experiment any time and without justification.

Without a habituation period, only a marginally difference could be found for the perception of reality of the environment, of which participants perceived a higher perception of reality of the environment using the VR-headset, in comparison to the 3D-CAVE. A possible explanation for this is that the VR-headset completely covers the eyes (Fuchs, 2017), receiving no longer visual stimuli from the real environment which might be easier to move one's consciousness to the virtual environment, and consequently might have impact on the perception of the reality of the VR-environment.

Based on our results, we can conclude that both VR-methodologies are equally good to be used among older adults ($\geq$65 years). General preference will be given to the test setup that will be completed in second place, indicating the importance of habituation to the virtual environment. Both VR-applications can therefore be used in future research, i.e. to identify which characteristics in the physical environment have an impact on cycling for transport using VR-applications. Using these future results, clear advice can be formulated to policy makers and urban designers and planners to develop more effective interventions. The advantage of the VR-headset in comparison to the 3D-CAVE, is that the VR-headset is more practical to use at different locations. Especially in regard to the older populations, it is more convenient to bring the test setup closer to the subjects themselves.

4.1. Strengths and limitations

The main strength of this study is the innovative experimental approach (i.e. the VR cycle through environment) used among this age group. A second strength was the controlled and standardized conditions of our experiments, the participants were able to cycle at the same bike, in the same position, for both experiments, i.e. 3D-CAVE and VR-headset. The obtained results could not be influenced by a difference in posture while cycling. Third, using virtual environments is appropriate for older adults as their movement limitations are reduced (Kahlert and Schlicht, 2015). Fourth, the questionnaire was interview-based, making the results more reliable (Britten, 1995). Finally, a cross-over design was used in the present study, in which the participants were randomly assigned to one of the two conditions, and then to the other condition as well. This design makes it possible for the sample to serve as its own control group. This within subjects comparison ensures the highest possible equality between the participants exposed to both conditions (Polit and Beck, 2017). However, to reduce the chance of a carryover effect, it is advisable to provide a washout period within the cross-over design (Johnson, 2010; Jones and Kenward, 2014; Mills et al., 2009; Polit and Beck, 2017). In the present study, this was only foreseen to a limited extent, more specifically the time needed to complete the questionnaire (see Fig. 1) which probably causes a carryover effect, also reflected in the research results. Additionally, it might be interesting for future research to investigate how long the training moment (exposure) in advance should be to start measuring responses. Second, we used the same environmental streets twice in order to make the comparison between the two methodologies as good as possible. However, it is also possible that habituation has occurred in the second experiment as they recognized the virtual environments from the first experiment. A third limitation was the over-representation of participants with a tertiary education (61.1%) compared with the statistics of the Flemish population (Belgian Federal Government, 2019). Finally, it was the first time that his experimental setup and representation of the virtual environment was used within the framework of this type of research, which involves some limitations, e.g. the lack of interaction with other road users, the environmental noise, or weather conditions. These technical issues can be upgraded in the future.

5. Conclusions

Based on our results, we can conclude that both VR-methodologies are equally good to be used in future research among older adults ($\geq$65 years). Additionally, there are no specific requirements for particular target groups regarding the kind of VR-application. General preference was given to the test setup that was completed in second place, indicating the importance of habituation to the virtual environment. Both VR-applications can therefore be used in future research, i.e. to identify which characteristics in the physical environment have an impact on cycling for transport using VR-applications. The advantage of the VR-headset in comparison to the 3D-

CAVE, is that the VR-headset is more practical to use at different locations. Especially in regard to the older populations, it is more convenient to bring the test setup closer to the subjects themselves. Independent of the methodology, women perceived a higher degree of simulator sickness than men, participants older than 75 years perceived more presence in comparison to participants younger than 75 years, and participants who had never been in contact with VR-applications perceived the environment as more realistic in comparison to participants who had at least once been in contact with VR-applications.

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Ethics approval and consent to participate

The study protocol was approved by the Ghent University Hospital Ethics Committee (registration number B670201834807) and all participants provided written informed consent before participation in the experiment.

Authors' contributions

BD, DVD, JVC, MM and LM contributed to the design of the study. LM and MM coordinated the development of the experimental setup. LM coordinated the data collection, analyzed the data and drafted the manuscript, assisted by all authors. All authors revised the manuscript for important intellectual content, and all authors read and approved the final version.

Declaration of competing interest

The authors have no conflicts of interest to declare.

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Appendices.

Table A.1
Descriptive statistics for the interaction effect between test sequence and methodology

M ± SD	
Presence_CAVE	3.7 ± 0.7
started with the 3D-CAVE	3.6 ± 0.7
started with the VR-headset	3.9 ± 0.7
Presence_HEADSET	3.8 ± 0.7
started with the 3D-CAVE	3.9 ± 0.7
started with the VR-headset	3.8 ± 0.8
Reality_CAVE	4.0 ± 0.8
started with the 3D-CAVE	3.8 ± 0.8
started with the VR-headset	4.2 ± 0.8
Reality_HEADSET	4.1 ± 0.8
started with the 3D-CAVE	4.1 ± 0.7
started with the VR-headset	4.1 ± 0.9
SSQ_CAVE	339.0 ± 121.4
started with the 3D-CAVE	355.7 ± 118.3
started with the VR-headset	321.6 ± 123.2
SSQ_HEADSET	363.3 ± 144.8
started with the 3D-CAVE	342.2 ± 156.3
started with the VR-headset	385.3 ± 129.7

M = mean; SD = standard deviation

List of abbreviations

PA Physical activity
VR Virtual Reality
3D-CAVE Computer Aided Virtual Environment

References

Ainsworth, B.E., Haskell, W.L., Whitt, M.C., Irwin, M.L., Swartz, A.N.N.M., Strath, S.J., Brien, W.L.O., Bassett, D.R., Schmitz, K.H., Emplaincourt, P., Jacobs, D.R., Leon, A.S., 2000. Compendium of Physical Activities : an update of activity codes and MET intensities. Med. Sci. Sport. Exerc. 32, 498–516.

Bangay, S., Preston, L., 1998. AN investigation into factors influencing immersion IN interactive virtual reality. Virtual Environ. Clin. Psychol. Neurosci. 43–51.

Baranowski, T., Anderson, C., Carmack, C., 1998. Physical Activity Interventions How Are We Doing ? How Might We Do Better ?, vol. 15.

Belgian Federal Government, 2019. Statistics Belgium. http://statbel.fgov.be/.

Boyd, D., 2014. Is the oculus rift sexist? http://qz.com/192874/is-the-oculus-rift-designed-to-be-sexist.

Britten, N., 1995. Qualitative Research Qualitative interviews in medical research. BMJ Clin. Res. 311, 251–253. https://doi.org/10.1136/bmj.311.6999.251.

Cerin, E., Nathan, A., Cauwenberg, J. Van, Barnett, D.W., Barnett, A., 2017. The Neighbourhood Physical Environment and Active Travel in Older Adults : A Systematic Review and Meta-Analysis, pp. 1–23. https://doi.org/10.1186/s12966-017-0471-5.

Cruz-neira, C., Sandin, D.J., Defanti, T.A., 1993. Surround-screen projection-based virtual reality : the design and implementation of the CAVE. In: SIGGRAPH, pp. 1–6.

Cubukcu, E., Nasar, J.L., 2005. Influence of physical characteristics of routes on distance cognition in virtual environments. Environ. Plan. B Plan. Des. 32, 777–785. https://doi.org/10.1068/b31191.

De Fré, B., De Martelaer, K., Philippaerts, R., Scheerder, J., Lefevre, J., 2011. Sportparticipatie en fysieke (in)activiteit van de Vlaamse bevolking. Huidige situatie en seculaire trend (2003-2009). Acco Academic.

Declercq, K., Janssens, D., Wets, G., 2016. Onderzoek Verplaatsingsgedrag Vlaanderen 5.1 (2015-2016) Tabellenrapport. Diepenbeek.

Dhondt, S., Kochan, B., Beckx, C., Lefebvre, W., Pirdavani, A., Degraeuwe, B., Bellemans, T., Int Panis, L., Macharis, C., Putman, K., 2013. Integrated health impact assessment of travel behaviour: model exploration and application to a fuel price increase. Environ. Int. 51, 45–58. https://doi.org/10.1016/j.envint.2012.10.005.

Duzmanska, N., Stronjny, P., Strojny, A., 2018. Can simulator sickness Be Avoided ? A review on temporal aspects of simulator sickness. Front. Psychol. 9 https://doi.org/10.3389/fpsyg.2018.02132.

Edwards, R.D., Mason, C.N., 2014. Spinning the wheels and rolling the dice: life-cycle risks and benefits of bicycle commuting in the. U.S. Prev. Med. (Baltim). 64, 8–13. https://doi.org/10.1016/j.ypmed.2014.03.015.

European Commission, 2014. "Sport and Physical Activity" Special Eurobarometer 412.

Fransson, P., Patel, M., Jensen, H., Lundberg, M., Tjernström, F., 2019. Postural instability in an immersive Virtual Reality adapts with repetition and includes directional and gender specific effects. Sci. Rep. 9, 1–10. https://doi.org/10.1038/s41598-019-39104-6.

Fuchs, P., 2017. Virtual Reality Headsets - A Theoretical and Pragmatic Approach, first ed. CRC Press, London. https://doi.org/10.1201/9781315208244.

Garrard, J., Rissel, C., Bauman, A., 2012. Health benefits of cycling. In: City Cycling.

Heft, H., Nasar, J.L., 2000. Evaluating environmental scenes using dynamic versus static displays. Environ. Behav. 32, 301–322. https://doi.org/10.1177/0013916500323001.

Howarth, P.A., Hodder, S.G., 2008. Characteristics of habituation to motion in a virtual environment. Displays 29, 117–123. https://doi.org/10.1016/j.displa.2007.09.009.

Huygelier, H., Schraepen, B., Ee, R. Van, Abeele, V. Vanden, Gillebert, C.R., 2019. Acceptance of immersive head- mounted virtual reality in older adults. Sci. Rep. 9, 1–12. https://doi.org/10.1038/s41598-019-41200-6.

Jackson, P.A., Pialoux, V., Corbett, D., Drogos, L., Erickson, K.I., Eskes, G.A., Poulin, M.J., 2016. Promoting brain health through exercise and diet in older adults: a physiological perspective. J Physiol J. Physiol. 594, 4485–4498. https://doi.org/10.1113/JP271270.

Johnson, D.E., 2010. Crossover experiments. Wiley Interdiscip. Rev. Comput. Stat. 2, 620–625. https://doi.org/10.1002/wics.109.

Jones, B., Kenward, M.G., 2014. Design and Analysis of Cross-Over Trials. New York.

Kahlert, D., Schlicht, W., 2015. Older people ' s perceptions of pedestrian friendliness and traffic safety : an experiment using computer-simulated walking environments. Int. J. Environ. Res. Public Heal. 12, 10066–10078. https://doi.org/10.3390/ijerph120810066.

Kennedy, R.S., Norman, L.E., 1993. Simulator sickness questionnaire: an enhanced method for quantifying simulator sickness. Int. J. Aviat. Psychol. 3, 203–220.

Koslucher, F., Haaland, E., Malsch, A., Webeler, J., Stoffregen, T., 2015. Sex differences in the incidence of motion sickness induced by linear visual oscillation. Aviat Med Hum Perform 86:787–793 Koslucher FC, Haaland E, Stoffregen TANo Title. Aerosp Med Hum Perform 86, 787–793.

Kozhevnikov, M., Rupali, P., 2012. Understanding immersivity : image generation and transformation processes in 3D immersive environments. Front. Psychol. 3, 1–10. https://doi.org/10.3389/fpsyg.2012.00284.

Mandl, B., Millonig, A., Klettner, S., McDonald, M., Hounsell, N., Wong, A., et al., 2012. Growing older, staying mobile: Transport needs for an ageing society. deliverable D4.2, Rep. No. FP7-TPT-2011-RTD-1) older people walking and cycling. GOAL Consortium, Austria.

Matas, N.A., Nettelbeck, T., Burns, N.R., 2015. Dropout during a driving simulator study : a survival analysis. J. Safety Res. 55, 159–169. https://doi.org/10.1016/j.jsr.2015.08.004.

Matthys, M., 2014. Mijn gemeente in meerdere dimensies: inspiratie uit het EFRO-project Gent 3D, in 4de dimensie. Stad Gent 28–29.

Mazzeo, R.S., Tanaka, H., 2001. Exercise Prescription for the Elderly, 31, pp. 809–818.

Mills, E.J., Chan, A., Wu, P., Vail, A., Guyatt, G.H., Altman, D.G., 2009. Design, analysis, and presentation of crossover trials. Trials 10, 27–33. https://doi.org/10.1186/1745-6215-10-27.

Mueller, N., Rojas-rueda, D., Cole-hunter, T., Nazelle, A. De, Dons, E., Gerike, R., Götschi, T., Int, L., Kahlmeier, S., Nieuwenhuijsen, M., 2015. Health impact assessment of active transportation : a systematic review. Prev. Med. 76, 103–114. https://doi.org/10.1016/j.ypmed.2015.04.010.

Munafo, J., Diedrick, M., Stoffregen, T.A., 2017. The virtual reality head - mounted display Oculus Rift induces motion sickness and is sexist in its effects. Exp. Brain Res. 235, 889–901. https://doi.org/10.1007/s00221-016-4846-7.

Natapov, A., Fisher-Gewirtzman, D., 2016. Visibility of urban activities and pedestrian routes : an experiment in a virtual environment. Comput. Environ. Urban Syst. 58, 60–70. https://doi.org/10.1016/j.compenvurbsys.2016.03.007.

Polit, D., Beck, C., 2017. Nursing Research: Generating and Assessing Evidence for in Nursing Practice, 10e ed. Wolters Kluwer, Philadelphia.

Portney, L.G., Watkins, M.P., 2009. Foundations of Clinical Research - Applications to Practice, Third. ed. Pearson Education, United States of America.

Rechel, B., Doyle, Y., Grundy, E., Mckee, M., 2009. How Can Health Systems Respond to Population Ageing ? WHO Europe, Denmark.

Schubert, T., 2003. The sense of presence in virtual environments: a three-component scale measuring spatial presence, involvement, and realnessitle. Zeitschrift für Medien. 15, 69–71. https://doi.org/10.1026//1617-6383.15.2.69.

Schubert, T., Friedmann, F., 1998. The Experience of Presence : Factor Analytic Insights 10.

Schubert, T., Friedmann, F., Regenbrecht, H., 1999. Embodied presence in virtual environments. In: Paton, R., Neilson, I. (Eds.), Visual Representations and Interpretations. Springer-Verlag, London, pp. 268–278.

Schubert, T., Friedmann, F., Regenbrecht, H., n.d Igroup Presence Questionnaire (IPQ) Overview [WWW Document].

Schuemie, M.J., Abel, B., Van Der Mast, C.A.P.G., Krijn, M., Emmelkamp, P.M.G., 2005. The effect of locomotion technique on presence, fear and usability in a virtual environment. Euromedia 129–135.

Smet, H. De, 2019. Naar een fietsveiligere stad via virtual reality. http://www.avs.be/avsnews/naar-een-fietsveiligere-stad-via-virtual-reality.

Steuer, J., 1992. Defining virtual reality: dimensions determining telepresence. J. Commun. 42, 73–93.

Van Cauwenberg, J., De Bourdeaudhuij, I., Clarys, P., De Geus, B., 2019. Older adults ' environmental preferences for transportation cycling. J. Transp. Heal. 13, 185–199. https://doi.org/10.1016/j.jth.2019.03.014.

Vanhaelewyn, B., De Marez, L., 2018. Imec.digimeter 2018 - Digitale Mediatrends in Vlaanderen.

Witmer, B., Singer, M., 1998. Measuring presence in virtual environments : a presence. Presence 7, 225–241.

Woodcock, J., Tainio, M., Cheshire, J., O'Brien, O., Goodman, A., 2014. Health effects of the London bicycle sharing system: health impact modelling study. BMJ 348, 1–14. https://doi.org/10.1136/bmj.g425.
World Health Organization, 2015. Physical Activity Strategy for the WHO European Region, pp. 14–17.
World Health Organization, 2011. Global Health and Aging. Geneva, Switzerland.
World Health Organization, 2010. Global Recommendations on Physical Activity for Health, pp. 1–60.
Yuan, B.S., Song, S., Zhang, Y., 2014. Experimental research in urban spatial cognition by using virtual reality technology. Athens J. Technol. Eng. 19–32.